

Analysis of Ca II emission lines in seven RS CVn systems

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Received November 25, 1985; accepted April 25, 1986

Summary. We report here new Ca II H and K emission line fluxes and equivalent widths for seven RS CVn binary systems, observed at several orbital phases. All the stars show enhanced chromospheric activity. With information from available spectra, an individual study for each star has been done. Double emission has been found for some systems in which perhaps the hotter component could be the more active. We have tested spectroscopically the model of localized active regions for the prototype RS CVn.

Key words: RSCVn binaries – chromospheric activity – Ca II emission

1. Introduction

The presence of Ca II (H and K) emission lines superimposed on the typical absorptions is the most remarkable characteristic, in the optical domain, of the existence of active chromospheres. In the solar chromosphere, the strongest Ca II emission appears associated with plages and the supergranulation network, which show magnetic field strengths larger than in surrounding zones. By analogy we can suppose that, in late type stars, these emissions are also associated with similar structures. Following the earlier work of Wilson (1978), many papers in the same framework have been devoted to show the existence of Ca II variability in the stellar activity: either long-term variability (indicating the presence of activity cycles similar to solar cycle) or short-term variability (indicating surface inhomogeneities).

The RS CVn systems are a stellar group possessing variability and whose contribution to understanding the stellar activity has been remarkable. Generically this class of stars, defined by Hall (1976), presents primary components of spectral type F-GV-IV, orbital periods between 1 and 14 days, and strong emission in H and K lines, Mg II (h and k), transition region lines, both low (C II, Si II) and high (Si IV, C IV, N V), and coronal X-rays. The emissions can be enhanced by a factor 10^2 – 10^3 with respect to the Quiet Sun. Other common features, but not present in all the systems, are quasi-sinusoidal distortions in the light curve outside of eclipse which migrate usually toward decreasing orbital phases, infrared and ultraviolet excesses, H_α emission, and secondary components around spectral type K0IV which are responsible for the emissions (Weiler, 1978). The peculiar behaviour of the light curve can be explained by means of the generally

accepted starspot model (Eaton and Hall, 1979), in which magnetic fields are presumed to be the origin of the dark spots in the photosphere and the exaggerated solar-like activity occurring in the chromosphere, transition region, and corona.

Observation of the more conspicuous activity indicators at several phases for these systems, along with photometric monitoring, allow us to know the relative distribution of active regions and spots on the stellar surface. Moreover, with knowledge of masses, radii, etc. of both components we have the possibility of making correlations between activity parameters and structural parameters.

In this paper we present a study of the appearance of the emission features in the H and K lines of Ca II for seven RS CVn binary systems, to look for variation in the emission fluxes as a function of orbital phase or phase of the photometric migrating wave. Such a correlation has been reported by some investigators (Baliunas and Dupree, 1982; Marstad et al., 1982) and is a promising source of information about the dark spot model.

In Table 1 we show the more important properties of these seven systems. Only three (RSCVn, Z Her and UX Com) are eclipsing and so their absolute parameters (masses and radii) are relatively well determined. The four remaining systems (σ^2 CrB, AS Dra, HD 108102, and HD 166181) are non-eclipsing; therefore effective temperatures, visual absolute magnitudes and bolometric corrections have been assigned in case they cannot be known in any other way.

For these seven systems we have computed equivalent widths and absolute fluxes of the H and K emission cores. A separate discussion for each star follows.

2. Observations and data reduction

Spectra centered at 3950 Å and covering 180 Å were obtained during the nights 2–3 and 3–4 of June 1985, with the 2.5-m Isaac Newton Telescope at the Observatorio del Roque de los Muchachos (La Palma). The spectrograph was the IDS (Intermediate Dispersion Spectrograph) with grating 2400 B and camera 2, and the detector was an IPCS (Image Photon Counting System). In order to achieve the maximum resolution ~ 0.1 Å/pixel – the grating was oriented blaze-to-camera.

The original images contain 25 scans, each with 2048 pixels. Standard flat-field exposures were obtained in order to correct the stellar spectra for pixel-to-pixel sensitivity variations. For each stellar observation, a Cu-Ar lamp exposure was made to

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Table 1. Stellar parameters

			P(days)		Sp. T.	M/M \odot	R/R \odot	T _{eff} (K)	d(pc)	Eclipse
HD 114519	RS CVn	4.7978	H	F4	V-IV	1.33	1.92	6500	145	Total (1)
			C	KO	IV	1.39	4.01	4685		
HD 163930	Z Her	3.9928	H	F4	IV	1.23	1.69	6580	75	Partial (2)
			C	KO	IV	1.10	2.60	5100		
	UX Com	3.6426	H	G2		0.95	1.0	5860	350	Total (3)
			C	K2	IV	1.12	2.5	4520		
						T _{eff} [*]	M _v [*]	B.C. [*]		
HD 146361	σ^2 CrB	1.1398		G0	V	6030	+4.6	-0.18	21	None (4)
				G0	V	6030	+4.6	-0.18		
HD 107760	AS Dra	5.4149	H	G3	V	5830	+4.8	-0.20	29.39	None
			C	KO	V	5250	+5.9	-0.31		
HD 108102		0.9616		F8	V	6200	+4.0	-0.16	86	None (5)
				F8	V	6200	+4.0	-0.16		
HD 166181		1.8094	H	G5	V	5400	+5.3	-0.19	-	None (6)

Notes to Table 1:

Symbols: (*) adopted quantities, except for HD 166181. (H) and (C) mean Hot and Cool. P is the orbital period.

- (1) Masses from Popper (1961) adopting $i=86^\circ$. Period from Berriman et al. (1983). Radii from Ludington (1978). Temperatures from Eaton and Hall (1979).
- (2) Masses, radii and temperatures from Tümer et al. (1984). Period from Kurutaç and Ibanoglu (1980).
- (3) Masses and radii from Popper and Ulrich (1977). Temperatures assigned.
- (4) Period from Bakos (1984).
- (5) Period from Kraft (1965).
- (6) Effective temperature and visual magnitude from Strömgren photometry (Giménez et al., 1986). Spectral type of the cool star is dM (Nadal et al., 1974).

provide an exact wavelength calibration. The spectra were corrected for atmospheric extinction by means of the semiempirical method of Hayes and Latham (1975). The detector response curve was constructed using the standard star HR 7469 (HD 185395), spectral type F4 V, whose Earth-observed fluxes were taken from Gluschneva (1982). After correction for this curve, the flux units are $\text{erg cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$. The image processing was done with the IHAP software available at the Villafranca Satellite Tracking Station (ESA, Madrid).

The measurement of equivalent widths and determination of fluxes have been made after a reconstruction of the absorption profiles following the method of Blanco et al. (1974); these authors suggest that the wing profiles can be extrapolated smoothly toward the line center in order to define the photospheric level.

To convert the Earth-observed fluxes (f in Table 2) into stellar surface fluxes (F in Table 2) we have utilized the radii and dis-

tances, if available, and the usual method. In the case of stars whose radius is unknown, the procedure of Blanco et al. (1982) has been used along with the Oke and Schild's (1970) calibration.

For the two components of σ^2 CrB and AS Dra, V arises from the distance and M_v values adopted according to the spectral type of the components. For HD 108102 (T111 Comae), V of each star has been computed assuming $d = 86$ pc, i.e., the distance to the Coma cluster. For HD 166181 we have obtained the visual magnitude and effective temperature from Strömgren photometry (Giménez et al., 1986).

Uncertainties in the measurement of the fluxes come from several sources. First, the atmospheric extinction curve for La Palma does not exist and, therefore, an approximate method has been applied. Perhaps a second source of error is the selected criterion to define the photospheric level. Linsky and Ayres (1978) suggest this procedure overestimates the photospheric

contribution. The error is larger if the emission peak is unshifted with respect to the absorption since, in this case, the reconstruction of the profile is sometimes doubtful. Third, the measurements are more exact in the K line than in the H line because the absorption at 3968.47 \AA is more contaminated with H_ϵ . We estimate this error to be around 10 or 15%. Fourth, errors in the surface fluxes arise from the factors $(R/d)^2$ or F_V/f_V (ratio of the surface flux to the Earth-observed flux, both in the V band, used in the Blanco et al. (1982) method quoted above); obviously, uncertainties will be larger in the second of these, in which a general calibration has been introduced.

It is difficult to estimate the total error in the surface fluxes but a reasonable upper limit could be around 25%.

3. Results and discussion

In Table 2 we present the results obtained. Column 3 gives the orbital phases for each image; an asterisk denotes that these values are discussed in the text. The remaining columns are self explanatory. In what follows we will comment separately on each system.

RS CVn

This star, the prototype of the class being discussed, has been extensively studied by many authors such as Popper (1961), Hall (1972), Eaton and Hall (1979). The light curve presents a wave outside of eclipse, indicating the existence of dark zones on the

Table 2. Results

	Image	Phase	$\lambda 3933.67 \text{ (K)}$			$\lambda 3968.47 \text{ (H)}$		
			$w_{\text{eq}}^{\circ}(\text{\AA})$	f_{obs}	F_{sup}	$w_{\text{eq}}^{\circ}(\text{\AA})$	f_{obs}	F_{sup}
RS CVn	1	0.83*	0.90	5.53(−13)	1.42(+6)	0.54	5.42(−13)	1.39(+6)
	2	0.84*	1.08	6.71(−13)	1.72(+6)	0.64	5.59(−13)	1.44(+6)
	3	0.04*	2.62	8.57(−13)	2.20(+6)	2.07	9.64(−13)	2.48(+6)
	4	0.05*	2.23	7.74(−13)	1.99(+6)	2.50	9.79(−13)	2.52(+6)
	5	0.07*	1.80	8.75(−13)	2.25(+6)	1.49	9.25(−13)	2.38(+6)
Z Her	1	0.27	0.44	3.07(−13)	5.02(+5)	0.42	3.30(−13)	5.40(+5)
	2	0.51	0.53	2.20(−13)	3.60(+5)	0.35	1.80(−13)	2.94(+5)
UX Com	1	0.47*	3.74	2.51(−13)	9.63(+6)	2.76	2.73(−13)	1.05(+7)
	2	0.73*	3.77	3.43(−13)	1.32(+7)	1.76	3.13(−13)	1.21(+7)
σ^2 CrB	1	0.06	1.35	1.29(−11)	1.01(+7)	0.87	1.22(−11)	9.55(+6)
	2	0.86	V 0.77	7.13(−12)	5.58(+6)	V 0.51	7.33(−12)	5.74(+6)
			R 0.58	5.25(−12)	4.11(+6)	R 0.42	5.92(−12)	4.63(+6)
	3	0.01	1.33	1.10(−11)	8.61(+6)	0.90	1.02(−11)	7.99(+6)
AS Dra		0.13	V 1.09	3.35(−13)	5.35(+5)	V 1.52	5.14(−13)	8.20(+5)
			R 0.93	2.85(−13)	7.45(+5)	R 0.41	1.36(−13)	3.56(+5)
HD 108102	1	− *	−	>4.90(−13)	>4.25(+6)	−	>4.40(−13)	>3.81(+6)
	2	− *	V 0.71	3.80(−13)	3.29(+6)	V 0.25	2.20(−13)	1.91(+6)
			R 0.66	3.30(−13)	2.86(+6)	R 0.41	3.10(−13)	2.69(+6)
HD 166181	1	0.93	2.63	2.49(−12)	4.64(+6)	1.71	2.49(−12)	4.64(+6)
	2	0.46	2.23	2.21(−12)	4.12(+6)	1.46	2.03(−12)	3.78(+6)

Notes to Table 2:

Phases marked with (*) are discussed in the text.

Flux units are $\text{erg cm}^{-2} \text{ s}^{-1}$.

The results for AS Dra arise after a two-gaussian deblending of the original profiles. The separation in components for the K line is doubtful.

(V) and (R) mean "Violet peak" and "Red peak".

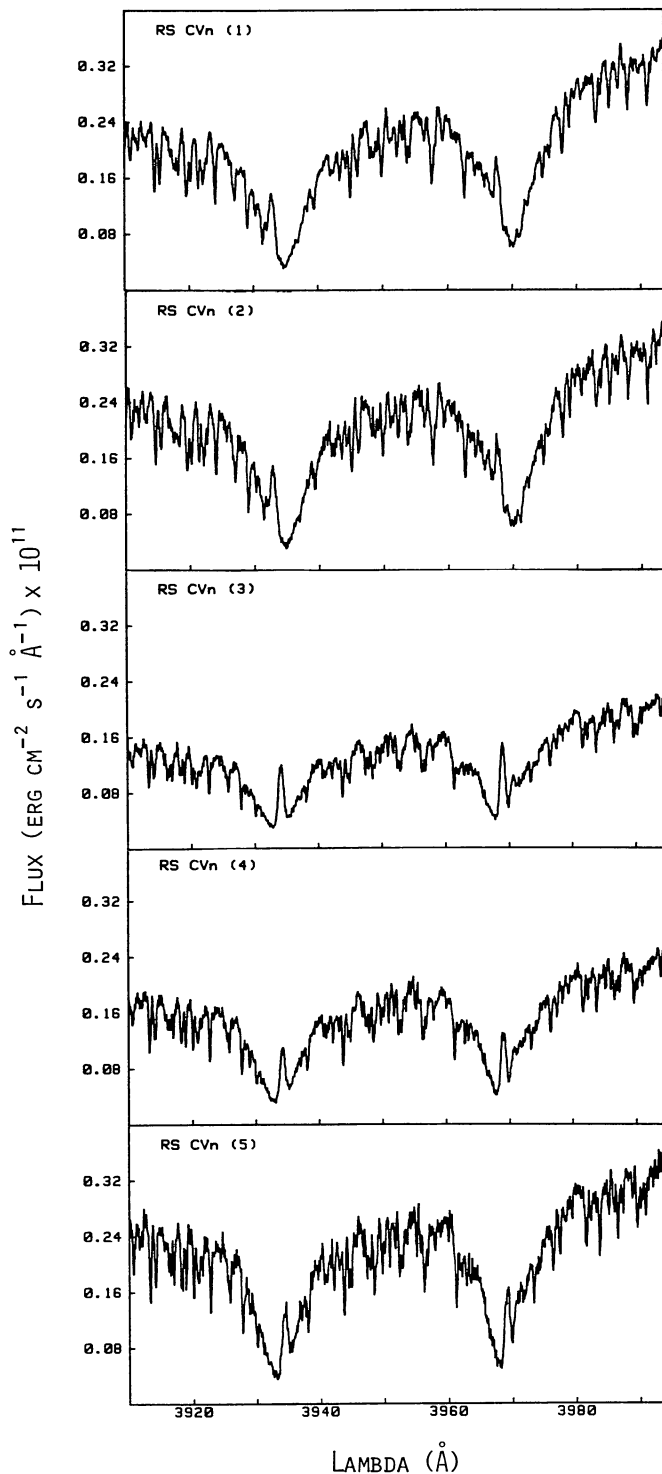


Fig. 1

surface of the active (cool) star. In Fig. 1 we show the five images obtained. Images (1) and (2) are taken before the secondary component begins to hide the primary component, images (3) and (4) correspond to the end of the primary minimum, and image (5) is again outside of eclipse. The continua of spectra (3) and (4) are lower than the continua of the other spectra because the main contribution to the received energy comes from the hot star, al-

though the emission indicates large activity arises from the cool component.

In order to estimate the orbital phases we have made use of several ephemerides:

$$\text{Min I} = (\text{J.D. Hel.}) 2438467.1282 + 4.797660E \text{ (Cristaldi, 1966)}$$

$$\text{Min I} = (\text{J.D. Hel.}) 2439834.471 + 4.79781E \text{ (Weiler, 1978)}$$

$$\text{Min I} = (\text{J.D. Hel.}) 2442861.366 + 4.79775E \text{ (Berriman et al., 1983)}$$

The results are not consistent with the shape of the spectra. We have measured carefully the relative shift among the 3927.933 Å and 3961.535 Å lines of the hot star and the K and H lines of the cool star. We obtain the relative radial velocities between the components for each observation. Using the orbital elements and the most recent orbital period (Berriman et al., 1983), one can compute the relative orbital velocity of the secondary relative to the primary ($\sim 176.2 \text{ km s}^{-1}$). From this we obtain the phases listed in Table 2.

The difference between the emission fluxes at phases 0.83 – 0.84 and the fluxes at phases 0.04 – 0.07 cannot be explained if the emission comes from the whole of the stellar surface. If we suppose an active region-responsible for the emission-situated on the hemisphere opposite the hot star, i.e., at longitude 170° and extending 165° in longitude, then we have a simple, though tentative, explanation for the behaviour of the flux. In Fig. 2 we have plotted the H + K flux normalized to the maximum value and the projection of the surface of the active region normalized to the surface seen at phase 0.04, both quantities against the orbital phase. We find good agreement between the observed fluxes and the projection factor. A more detailed solution could be achieved by means of monitoring the star over the entire orbit. The presence of asymmetric profiles in images (3), (4), and (5) indicates that perhaps there are active regions distributed over the stellar surface with different relative velocities.

Z Her

Two spectra of this partially eclipsing binary are presented in Fig. 3. Image (1) was taken with the system at quadrature and image (2) corresponds to phase 0.51 at which a fraction 0.28 of the secondary star is hidden. Phases here were computed with the ephemeris $\text{Min I} = (\text{J.D. Hel.}) 2441111.8211 + 3.9928012E$ of Kurutaç and Ibañoğlu (1980). Both spectra present the same shape although spectrum (1) is a little bit higher than spectrum (2). The H + K flux received during eclipse is ~ 0.6 times the flux received at quadrature, so that a fraction of the active regions could be situated in the eclipsed zone.

This star is the least active of the sample. The activity in upper atmospheric levels also is more attenuated than in other stars of this group. Many transition region features, for instance $1808 + 1817 \text{ Å}$ (Si II), 1657 Å (C II), and $1394 + 1403 \text{ Å}$ (Si IV) do not appear in the spectrum and the most prominent lines in this spectral region (1240 Å (N V), 1550 Å (C IV), 2800 Å (Mg II)) are weaker than in other members of the RSCVn family (Fernández-Figueroa et al., 1985 and Fernández-Figueroa et al., 1986).

UX Com

We present two spectra of this eclipsing binary in Fig. 4. As can be seen in image (1) the emissions are slightly red-shifted

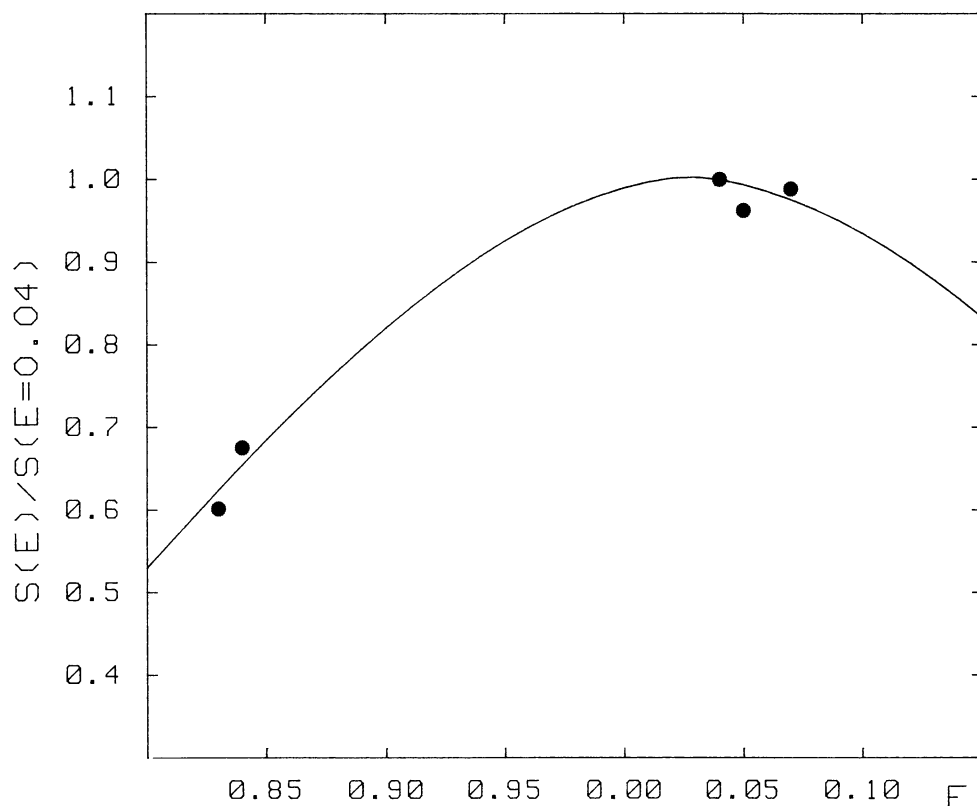


Fig. 2. H + K flux (dots) for RS CVn and the projected area of an active region placed at $\lambda = 170^\circ$ and extending 165° (curve), both normalized at their maximum value at phase $E = 0.04$ and both plotted versus orbital phase. The agreement supports the theory that the emission does not arise from the whole of the star but from localized zones

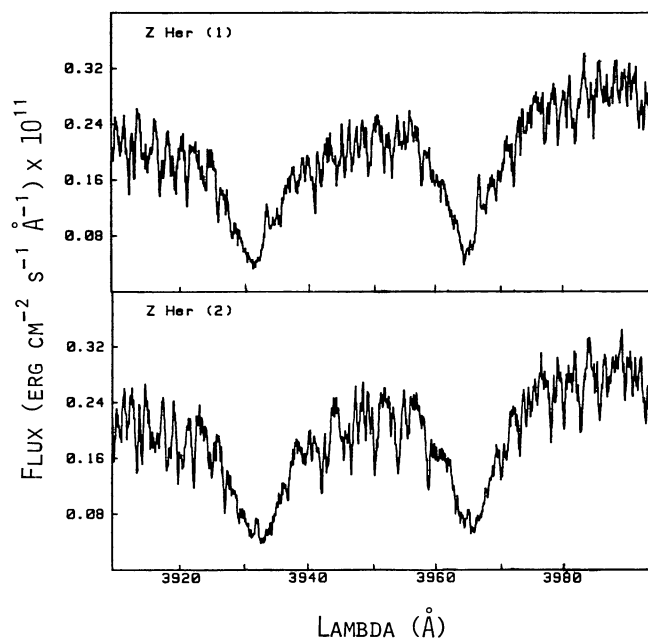


Fig. 3

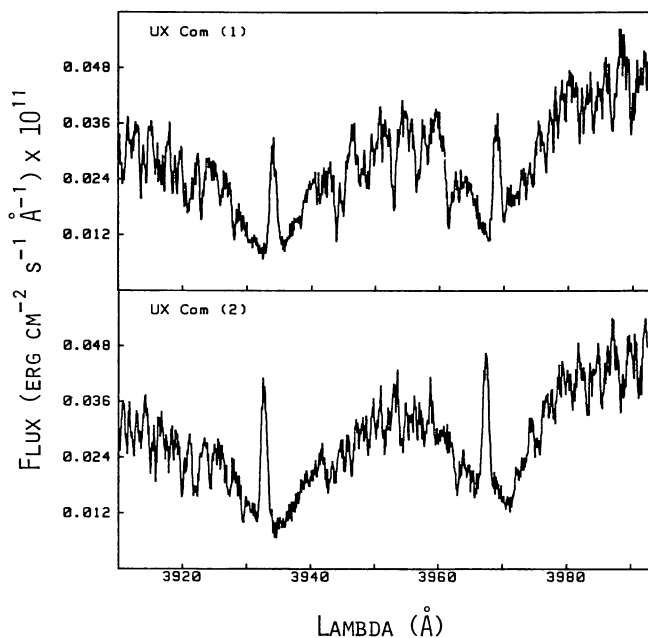


Fig. 4

and in image (2) the lines are blue-shifted. Again we have a problem with the computation of the orbital phases using the ephemeris $\text{Min I} = (\text{J.D. Hel.}) 2425798.328 + 3.642583E$ of Hall and Kreiner (1980). This yields $E = 0.51$ for image (2), which is

clearly inconsistent because in such a case the lines should be practically unshifted. The problems found with orbital phases probably are a consequence of the period changes observed in many RSCVn systems. The long-term period changes in most

RSCVn binaries as period decreases. Hall and Kreiner (1980) point out that UX Com (and also RSCVn and Z Her) shows period changes in both directions, perhaps due to anisotropic mass loss of the cool star by a convection-driven stellar wind mechanism. From measurement of the radial velocities, like in RSCVn, we determine that image (1) was taken at phase 0.47 ± 0.02 , i.e., beginning or within the secondary eclipse, and image (2) corresponds to phase 0.73, with the system at quadrature. In the first position a fraction $0.085 - 0.16$ of the secondary is hidden, so that the continuum is ~ 0.9 times lower than that of the system outside eclipse. The ratio of fluxes from image (1) to fluxes from image (2) is ~ 0.80 ; it seems apparent that the flux emitted by the facing hemisphere of the cool star-taking into account the contribution of the eclipsed portion- is a little bit ($\sim 10\%$) smaller than the emission arising from the hemisphere seen at quadrature. Nevertheless, errors in the reconstruction of the profiles, especially for the H line in image (2), are such that this result should be taken with care.

σ CrB

This system is a pair of stars, separated by $5''.3$ with an eccentric orbit ($e = 0.78$) and an orbital period of 1000 years. The faint component (σ^1 CrB \equiv HD 146362) is a star of spectral type G1 V (Hoffleit and Jaschek, 1982) and the bright star (σ^2 CrB \equiv HD 146361) is a double-lined and double-emission spectroscopic

binary. σ^2 CrB is a non-eclipsing detached system and both components are main-sequence stars; their individual spectral types are unknown, although the composite spectrum is around G0 V (Abt, 1981).

In Fig. 5 we can see the three available images. Spectra (1) and (3) correspond to phases 0.06 and 0.01 and image (2) was taken at phase 0.86 according to the curve of radial velocities from Bakos (1984). The secondary component, with blue-shifted lines in image (2), is 1.3 times more active than the primary component. We have measured the position of the deeper absorption features in spectrum (2) with respect to the emission peaks of both stars. The distance among these absorption lines and the weaker peaks (red-shifted lines) is the same as that among the emission peaks and the absorption features in spectrum (3). Therefore, the component contributing with deeper absorptions (perhaps slightly larger metallicity or lower temperature?) is the less active. We have tried to fit the continuum by means of several combinations of spectral types retrieved from the KPNO Library of Stellar Spectra (Jacoby et al., 1984), but our wavelength range is too small and we cannot in this way discern the spectral type of the components.

Ca II observation of σ^2 CrB presented by Bopp (1984) shows emission of equal intensity in both stellar components. Surface fluxes computed by Bopp are comparable to those in Table 2 of this work, taking into account the errors involved by both procedures, with the estimated $V - R$ in the Bopp paper having introduced uncertainties of a factor ~ 2 in his Ca II flux measures.

When the spectra were taken, a convenient position angle of the slit made it possible to obtain the spectrum of σ^1 CrB in the same image containing the spectrum of the spectroscopic pair. Our analysis shows that this star is not active.

AS Dra

Only one image is available for this star, seen in Fig. 6. The orbital phase computed with the ephemeris T (zero phase) = (J.D. Hel.) $2435926.055 + 5.414905E$ of Kukarkin et al. (1969) is 0.13; therefore the difference in radial velocity between the components is small. In Fig. 7 one can observe an asymmetry of the same shape in the red wings of the emission lines. Since the two stars are late enough in spectral type to be convective, perhaps the emission arises from both components. We have deblended the H and K lines by means of a two-gaussian fitting. In the H line the two gaussian peaks are separated by 0.4 \AA (31 km s^{-1}),

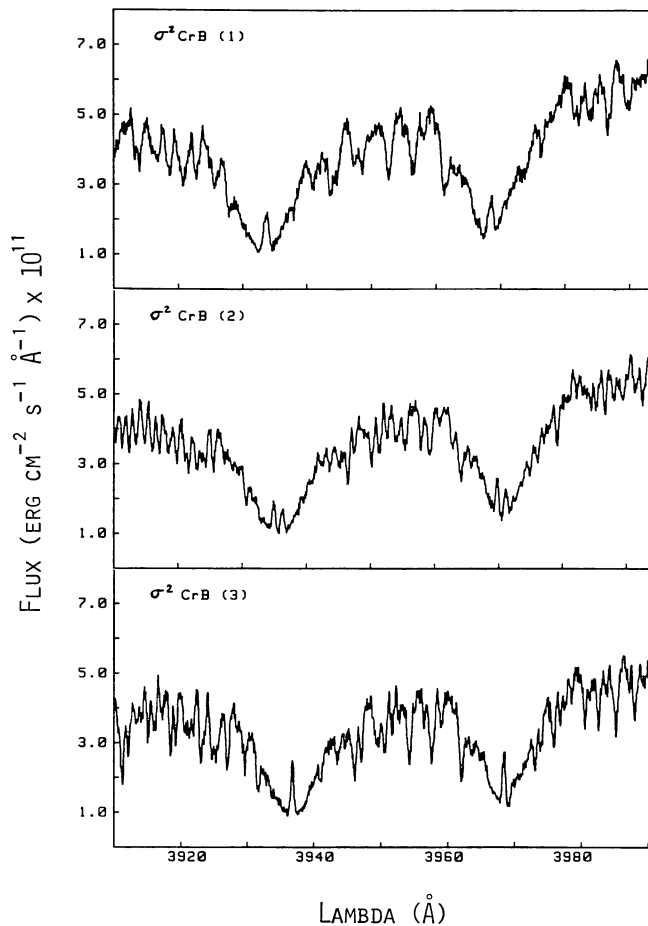


Fig. 5

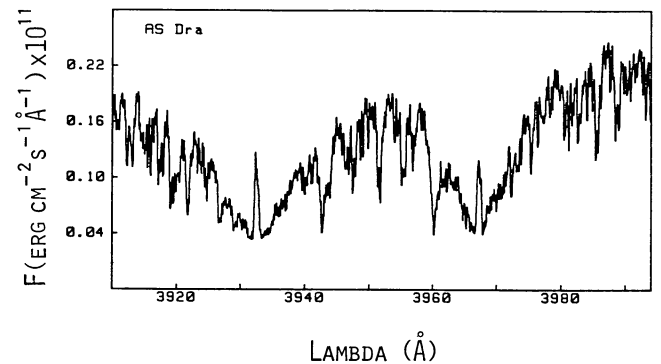


Fig. 6

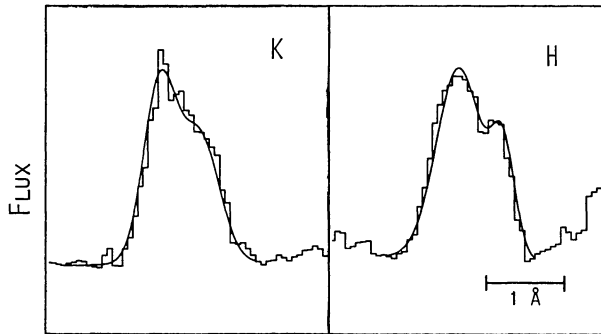


Fig. 7. H and K emission lines for AS Dra. The asymmetries of the same shape in both lines suggest that the emission comes from both components. Over the profiles we show the sum of the two gaussians by which each line has been deblended

with the blue component (corresponding to the hot star) contributing with 79% of the total emission flux and the red component (arising from the cool star) with 21%. The K line also has an asymmetric profile, but the separation is less reliable. However again we obtain a distance of 0.4 \AA between peaks and contributions of 54% (hot star) and 46% (cool star) to the total emission received from this line. After computation of surface fluxes, the total Ca II flux (H + K) arising from the hot star is larger than that one arising from the cool star. Therefore, either by the criterion of emission strength or surface flux, if the orbital phase is correct, the hot star would be the more active component of the system.

HD 108102

This star is a double-lined spectroscopic system with emission arising from both components. Image (1), seen in Fig. 8, presents the lines overlapped, but in image (2) the emission lines are slightly better defined. We have computed the orbital phases with help of T (zero phase) = (J.D. Hel.) 2438423.825 + 0.9616E

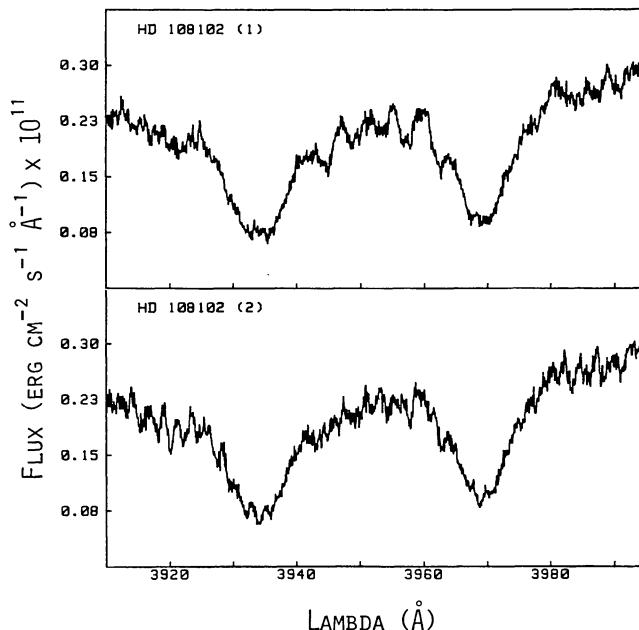


Fig. 8

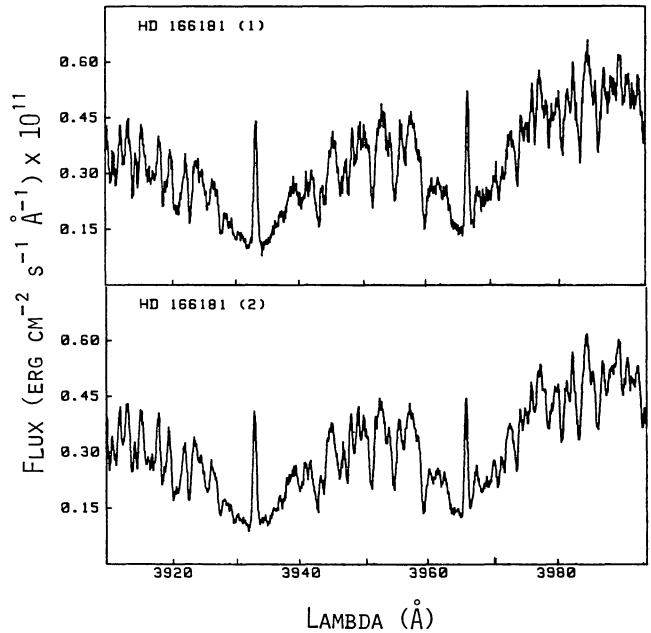


Fig. 9

(Kraft, 1965) but the results, 0.94 and 0.99, respectively, are not in agreement with the appearance of the spectra. If one measures the distance between the emission peaks, the relative velocity of the components is around $140 - 170 \text{ km s}^{-1}$, i.e., near phases 0.13, 0.38, 0.63 or 0.86 according to the radial velocity curve of Kraft (1965). Therefore, with only these data we are not able to establish which star is the responsible for the blue-shifted lines and which one for the red-shifted lines.

HD 166181

Two images are available for this star, at phases 0.93 for (1) and at 0.46 for (2) according to the ephemeris T (zero phase) = (J.D. Hel.) 2441930.487 + 1.8098368E, which has been obtained from the ephemeris T (periastron passage) = 2441931.127 + 1.8098368E (Nadal et al., 1974) corrected to give orbital phases referred to the instant when the secondary star is in front. Both spectra are identical although they were taken at opposite phases. The emission lines are unshifted with respect to the absorption lines, so we can confirm that the hot star is the active component of the system, supporting the conclusion of Nadal et al. (1974); these authors have observed that H and K lines can be used to measure radial velocities, the results being similar to those deduced from the absorption lines, so that the main contributing star to the continuum and absorption features (hot component) is also the source of activity (see Fig. 9).

Surface fluxes presented in this work are comparable to those given by Bopp (1984) within the error estimates.

Fekel et al. (1986) report the observation of a very strong lithium line in the 6700 \AA region and they conclude that such a line present in a late-type dwarf indicates that the star is very young. These authors classify this binary as an early-type BY Dra-like system.

4. Final remarks

Our primary result is the presentation of new H and K Ca II emission fluxes of seven RSCVn systems, extending the data

sample now available. Some interesting facts have been pointed out in this study:

(i) A spectroscopic confirmation of the presence of localized active regions in the active component of the binary RSCVn.

(ii) The observation of emission arising from both stars when they have similar spectral types, indicating that both components are active, as well as the possibility that in σ^2 CrB and AS Dra the cool star is not the more active, contrary to the general behaviour of most RSCVn binaries.

(iii) Indirect evidence of the existence of period variability or poorly determined periods in some systems, through problems found with the computed orbital phases when using published ephemerides in conjunction with recent radial velocities measurements.

We stress the importance of new determinations of periods and recent times of minimum to obtain an exact correlation between activity and orbital phase. In the same sense, new and more accurate radial velocity curves should be obtained, especially in the case of non-eclipsing binaries.

Finally, we want point out that the classification as RSCVn-like stars of some systems studied here can be questioned; so, following the discussion by Fekel et al. (1986), taking into account the evolutionary status of the chromospherically active systems, σ^2 CrB and HD 166181 could be included in the group of early-type BY Dra stars.

Acknowledgements. The Isaac Newton Telescope, on the island of La Palma, is operated by the Royal Greenwich Observatory at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

We are grateful to the VILSPA staff for the use of their facilities. We thank Dr. R. González Riestra and Dr. J. Zamorano for help with IHAP use.

The authors are indebted to an anonymous referee for his critical reading of the manuscript and valuable comments.

This work has been supported by the Spanish Comisión Asesora de Investigación Científica y Técnica (CAICYT No. 2254/83).

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